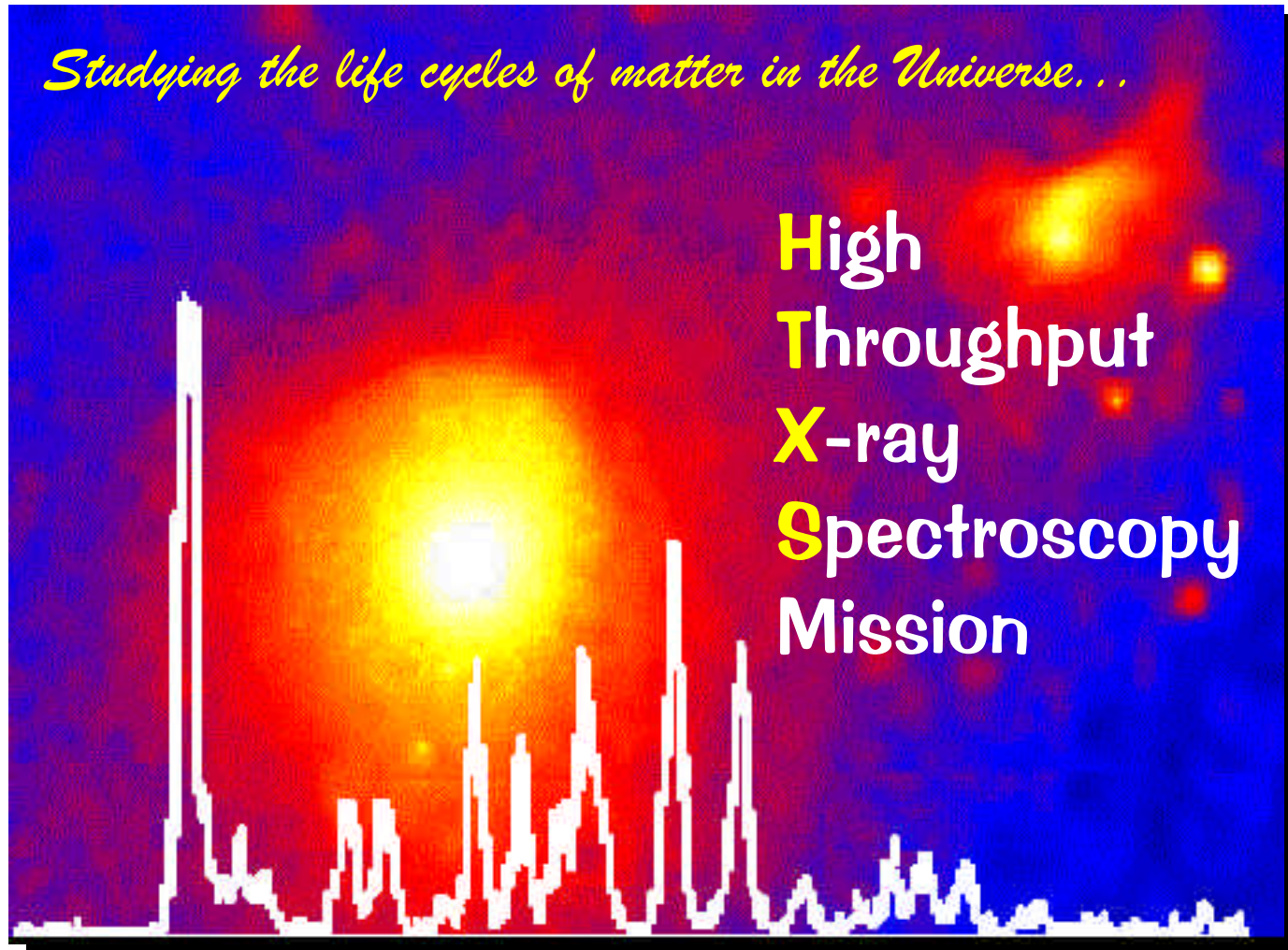
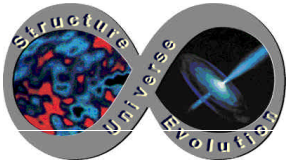


# The High Throughput X-ray Spectroscopy (HTXS) Mission

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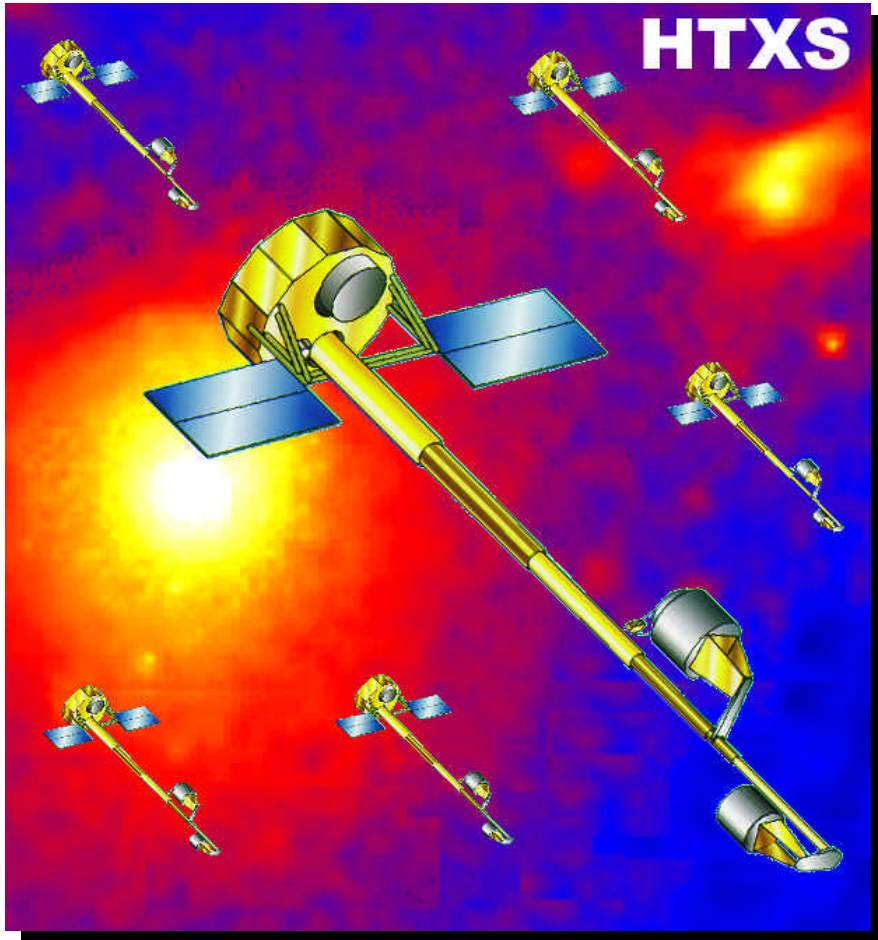
Nicholas White (GSFC) and Harvey Tananbaum (SAO)



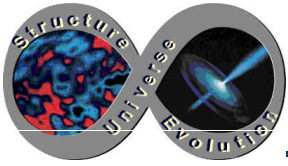


# High Throughput X-ray Spectroscopy Mission

*Studying the life cycles of matter in the Universe*



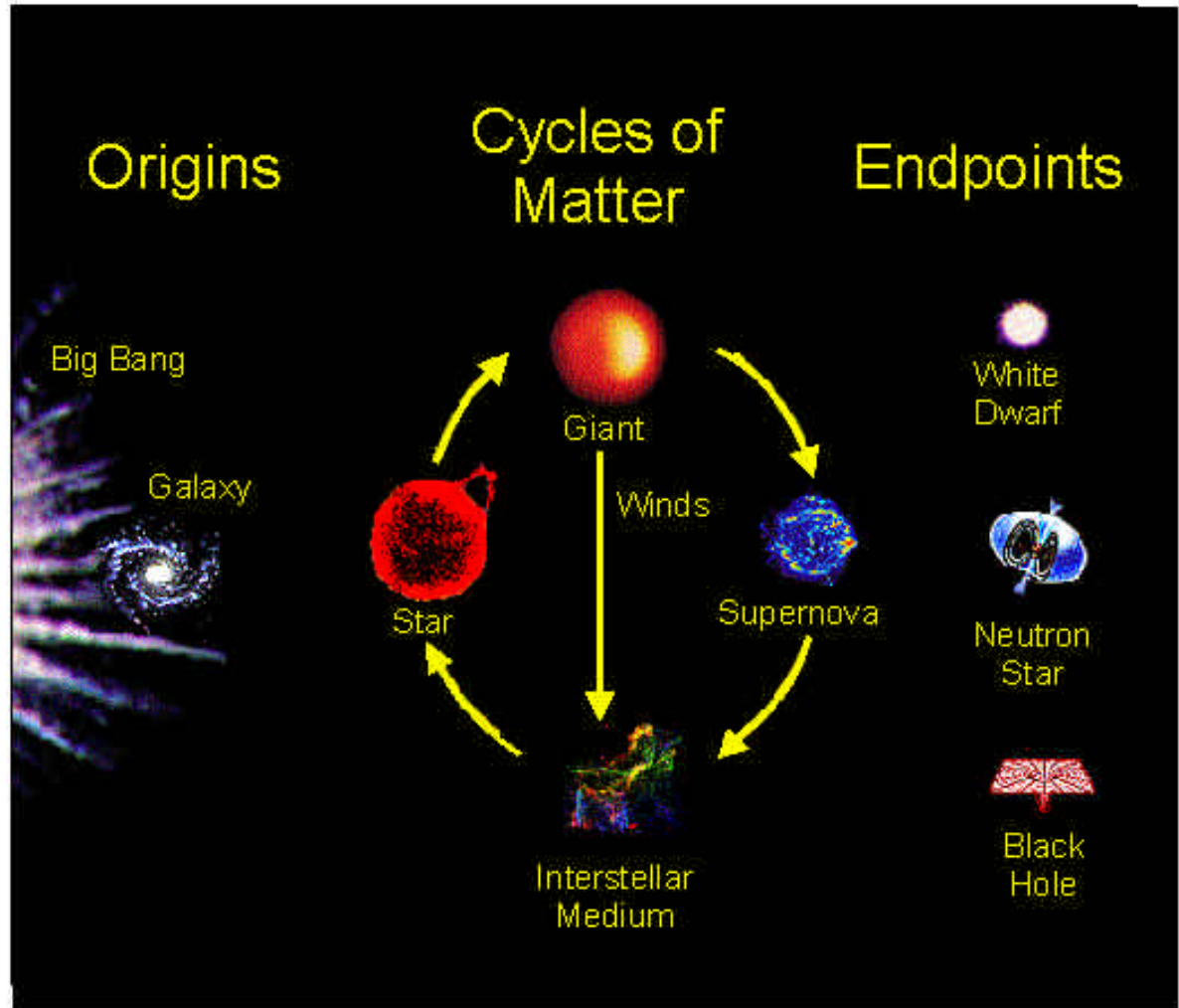
- Key scientific goals
  - Elemental abundances and enrichment processes throughout the Universe
  - Parameters of supermassive black holes
  - Plasma diagnostics from stars to clusters
- Mission parameters
  - Effective area: 15,000 cm<sup>2</sup> at 1 keV  
*150 times AXAF for high resolution spectroscopy*
  - Spectral resolving power: 3,000 at 6.4 keV  
*5 times Astro-E calorimeter*
  - Band pass: 0.25 to 40 keV  
*100 times increased sensitivity at 40 keV*



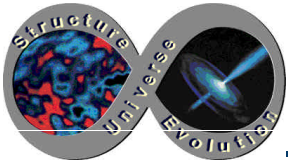
# Studying the Life Cycles of Matter with the HTXS Mission

Obtain high quality X-ray spectra for all classes of X-ray sources over a wide range of luminosity and distance to determine:

- the abundance of elements with atomic number between Carbon and Zinc ( $Z=6$  to 30) using line to continuum ratios
- the ionization state, temperature, and density of the emission region using plasma diagnostics
- the underlying continuum process with a broad bandpass
- dynamics from line shifts and line broadening

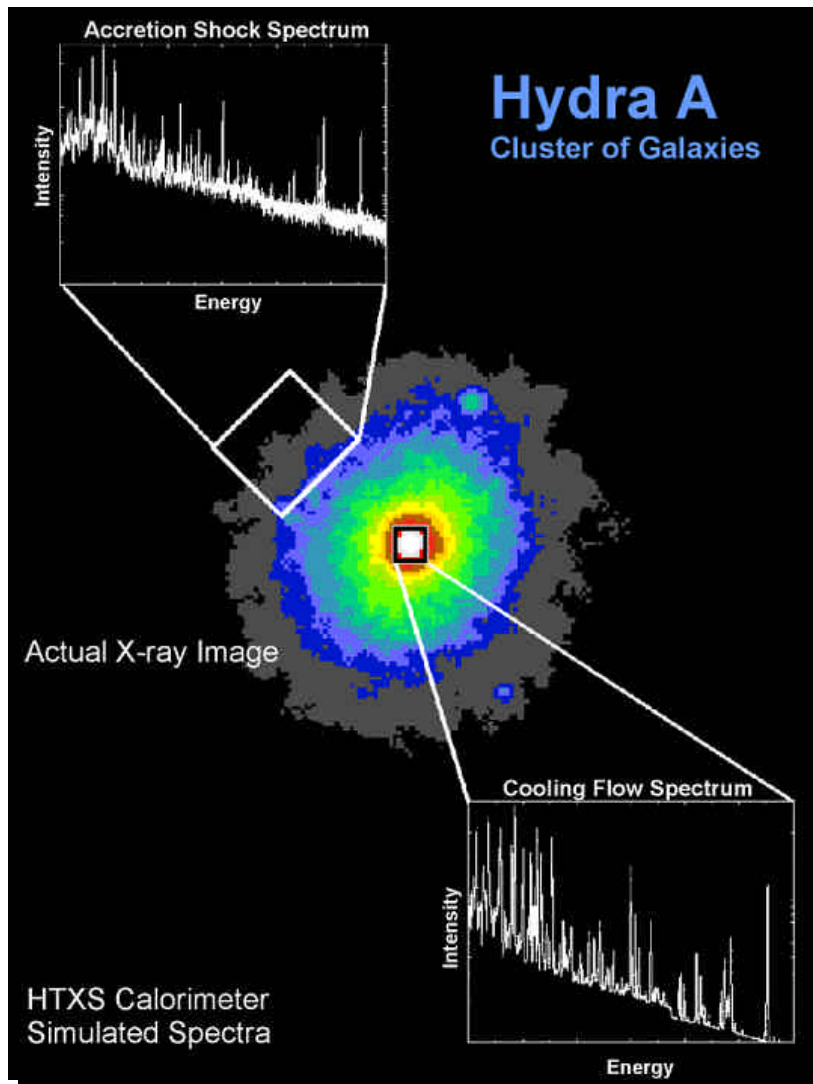






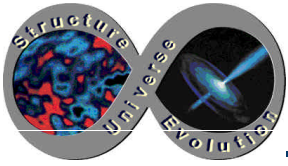
# HTXS Observations of Clusters of Galaxies

Baryon content of Universe is dominated by hot X-ray emitting plasma

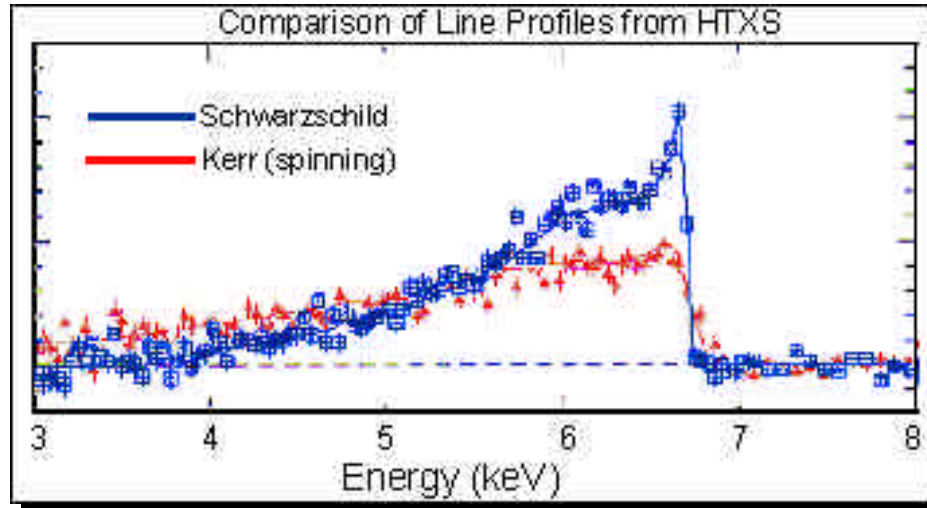


HTXS cluster observations essential for understanding structure, evolution, and mass content of the Universe

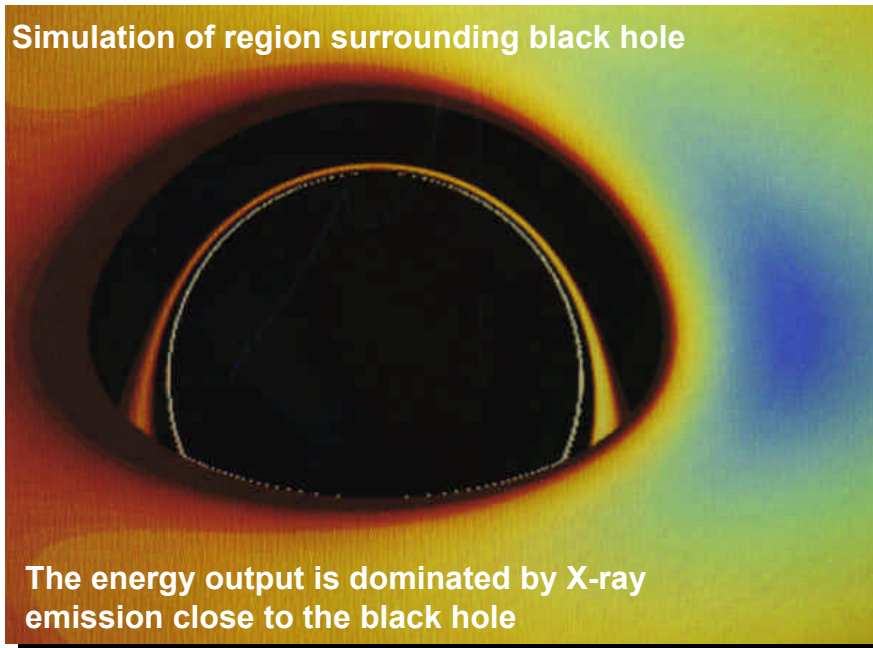
- Observe epoch of cluster formation and determine changes in luminosity, shape, and size vs redshift
- Measure abundances of elements from carbon to zinc, globally mapping generation and dissemination of seeds for earth-like planets and life itself
- Map velocity profiles, probing dynamics and measuring distributions of luminous and dark matter



# HTXS Will Determine the Nature of Super-Massive Black Holes

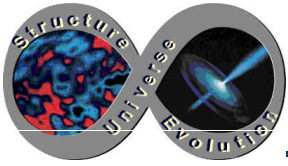


Simulation of region surrounding black hole



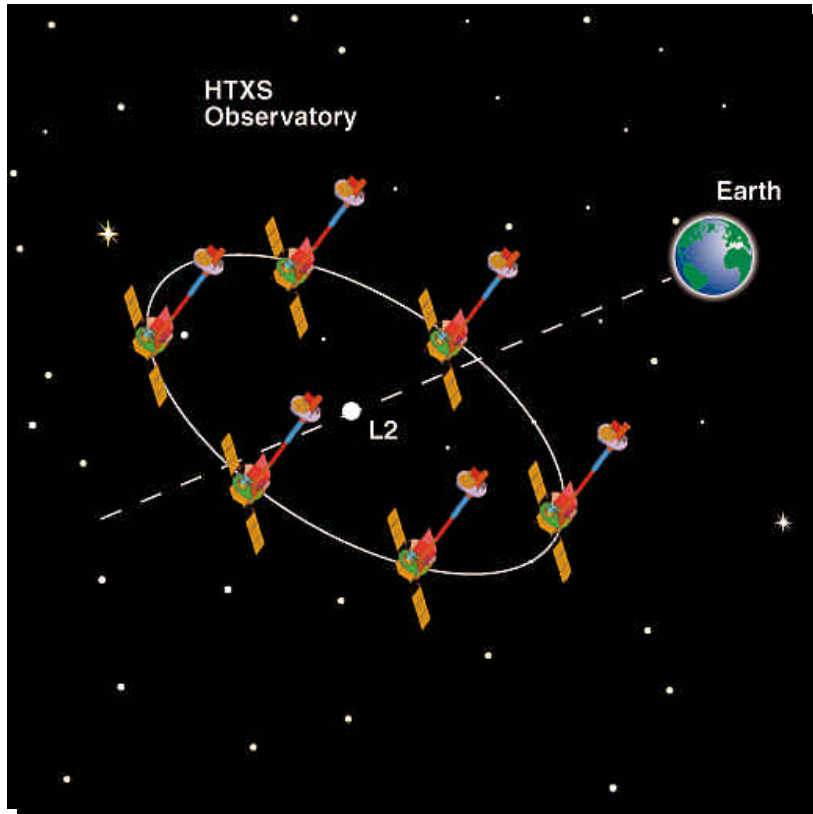
The energy output is dominated by X-ray emission close to the black hole

- HTXS will determine black hole mass and spin using iron K line
  - Spin from line profiles
  - Mass from time-linked intensity changes for line and continuum
- Trace black hole spin and mass over cosmic time from epoch of galaxy formation to present
- Relativistically broadened iron lines probe inner sanctum near black holes, testing GR in strong gravity limit



# A Multi-Satellite Approach to Large Collecting Area

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To achieve 15,000 cm<sup>2</sup> effective area on a single satellite requires a Titan-class launch.

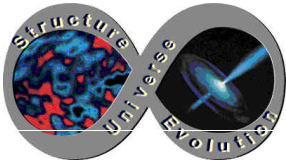
An alternative low-risk approach to achieve large X-ray collecting area is to utilize six identical low-cost Delta-class satellites.

Launch intervals of three months.

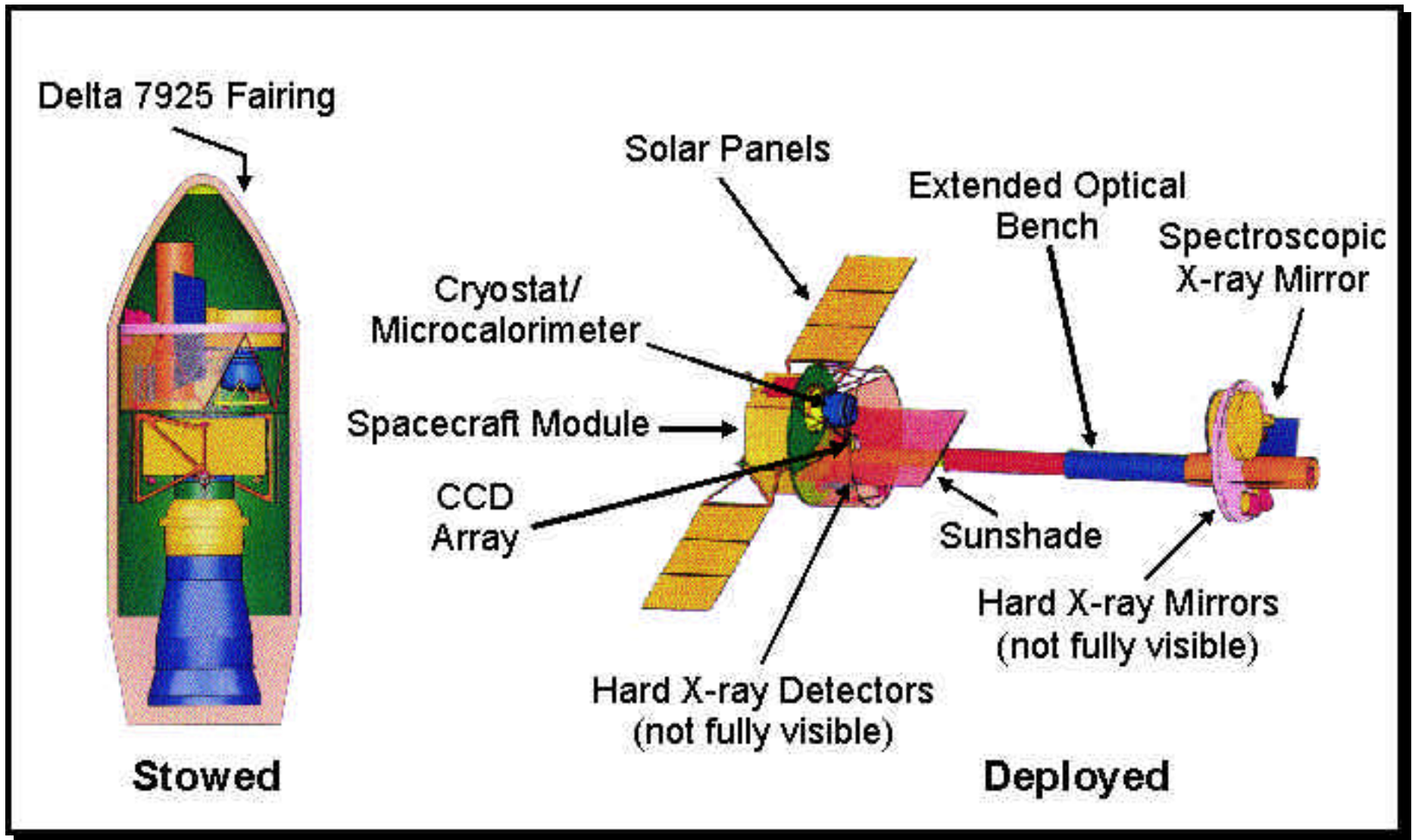
Facilitate simultaneous viewing and high efficiency by using libration point orbit.

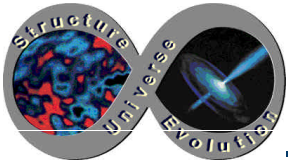
The telescopes require a focal length of 8.5 m and use an extendible optical bench to allow a Delta-class launch.

Each spacecraft design lifetime is three years, with consumables targeted for a five-year mission.



# HTXS Reference Design





# HTXS Requirements Flow Down

## Science Goals

Elemental Abundances  
and Enrichment  
throughout the Universe

Parameters of  
Supermassive  
Black Holes

Plasma Diagnostics  
from Stars to  
Clusters

## Measurement Capabilities

Minimum effective area: 15,000 cm<sup>2</sup> at 1 keV  
6,000 cm<sup>2</sup> at 6.4 keV  
1,500 cm<sup>2</sup> at 40 keV

Telescope angular  
resolution: 15" HPD from 0.25 to 10 keV  
1' HPD above 10 keV

Minimum spectral  
resolving power ( $E/\Delta E$ ): 300 from 0.25 to 6.0 keV  
3000 at 6 keV  
10 at 40 keV

Band Pass: 0.25 to 40 keV

## Key Technologies

### High Throughput Optics

- *Lightweight ó 250 kg*
- *Replicated shells and segments*

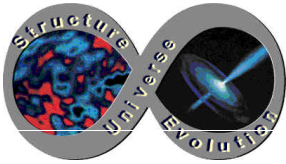
### High Spectral Resolution

- *2 eV microcalorimeter arrays*
- *Coolers*
- *Lightweight gratings*
- *CCD arrays extending to 0.25 keV*

### Broad Bandpass

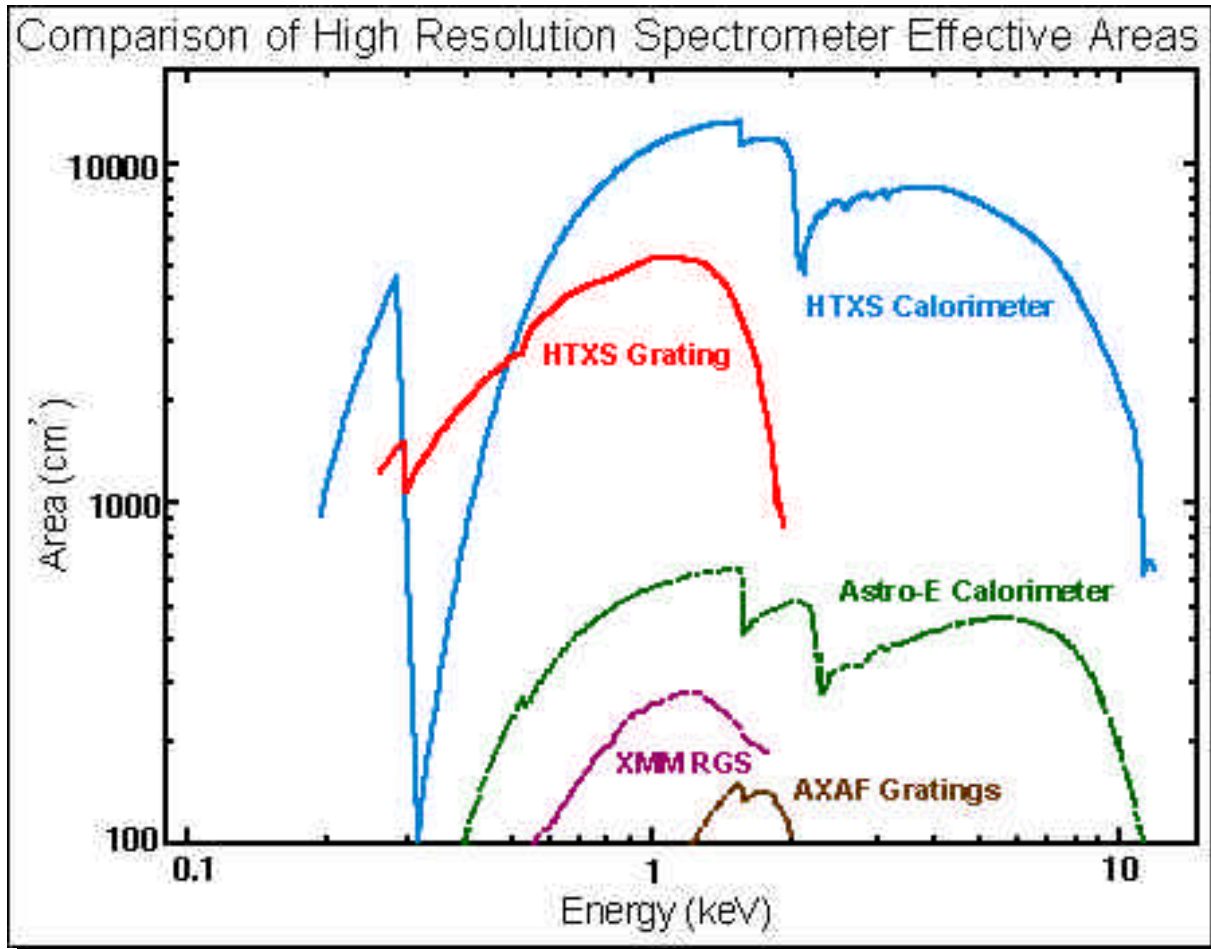
- *Multilayer optics*
- *CdZnTe detectors*





# HTXS Advanced Capabilities

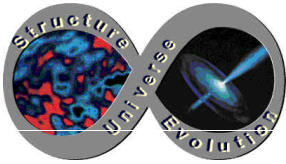
## I. High Throughput



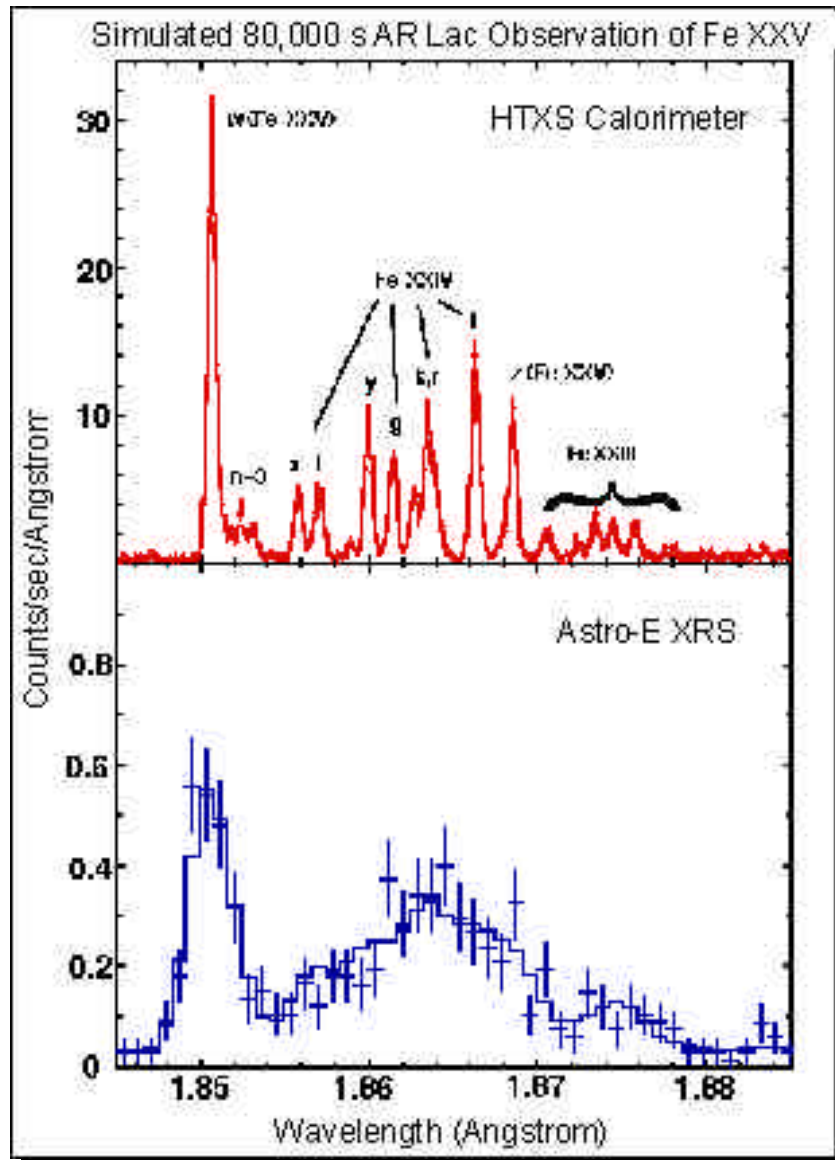
A 20-100 fold gain in effective area for high resolution X-ray spectroscopy

High throughput optics plus high quantum efficiency calorimeters

Lightweight reflection gratings maintain resolution and coverage at low energies (< 1 keV)



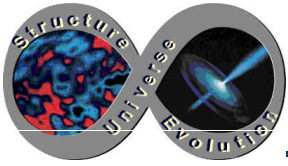
## HTXS Advanced Capabilities II. High Spectral Resolution



### *The Next Generation Microcalorimeter Array*

High quantum efficiency with the capability to map extended sources

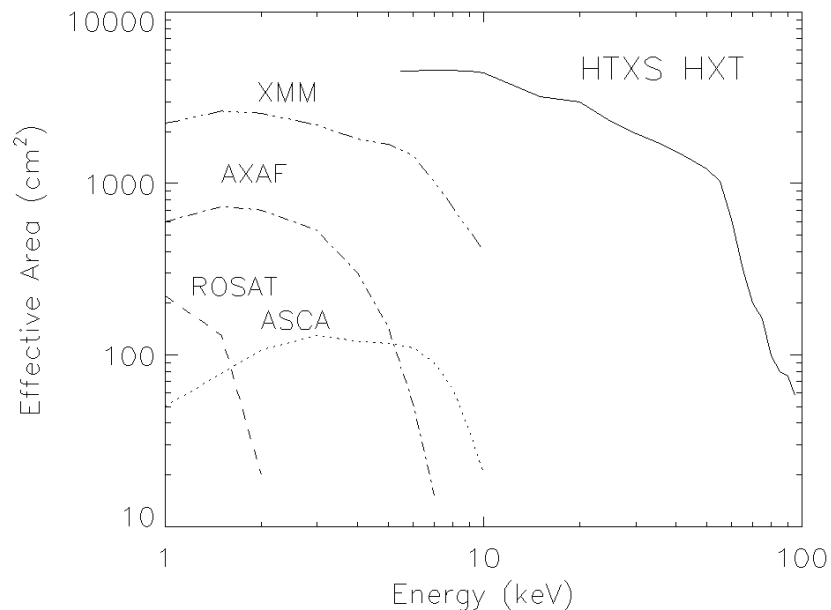
- A factor of 5 improvement (to 2 eV) in spectral resolution
- Successor to the calorimeter to be flown on Astro-E (2000-2002)
- At Iron K, 2 eV resolution gives a velocity diagnostic of 10 km/s



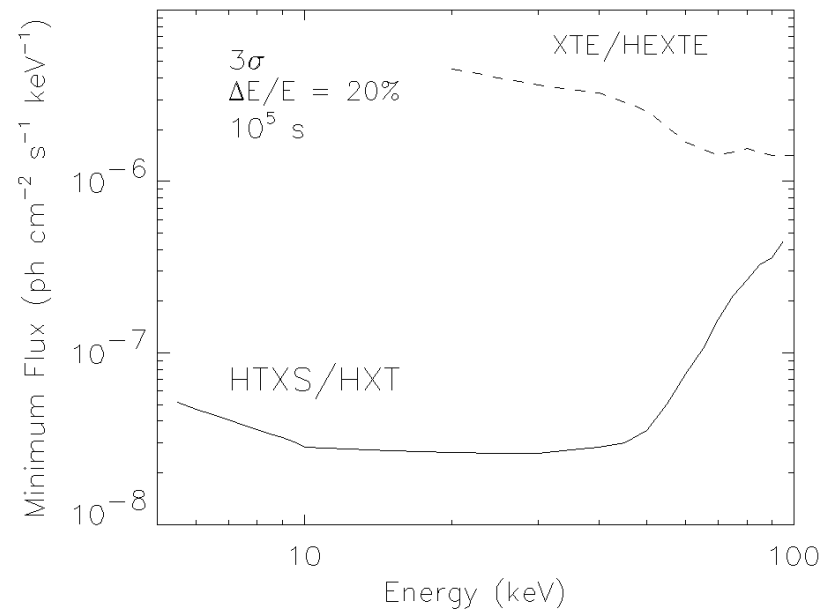
# HTXS Advanced Capabilities

## III. Broad Bandpass

Multilayer coatings to enhance high energy response

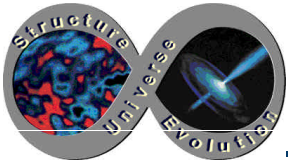


Effective area as a function of energy for baseline HXT design.

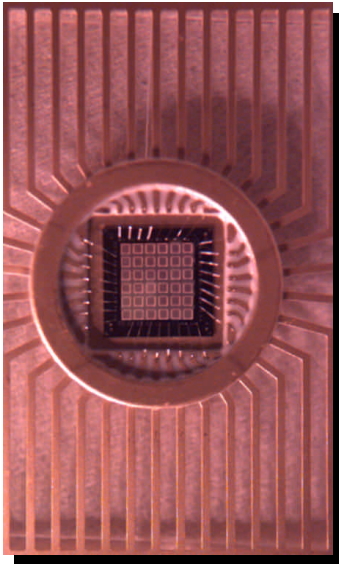


Continuum sensitivity as a function of energy for baseline HXT design

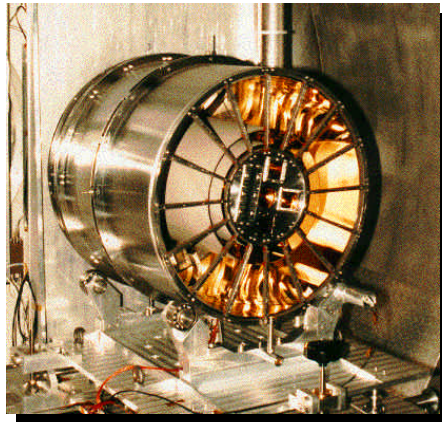
- No previous instrument has employed focusing in the Hard X-ray band
- Dramatic sensitivity improvements will be achieved



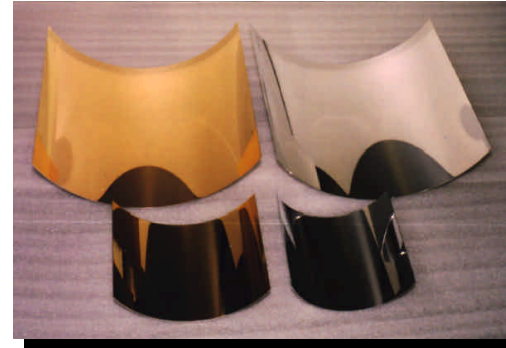
# HTXS Technology Requirements



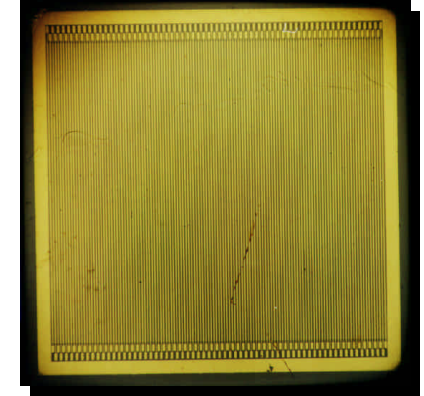
Microcalorimeters



Grazing Incidence  
X-ray Optics



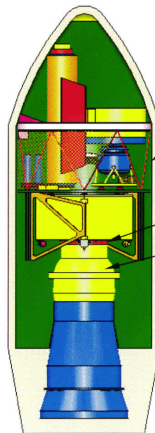
Multilayer Coatings



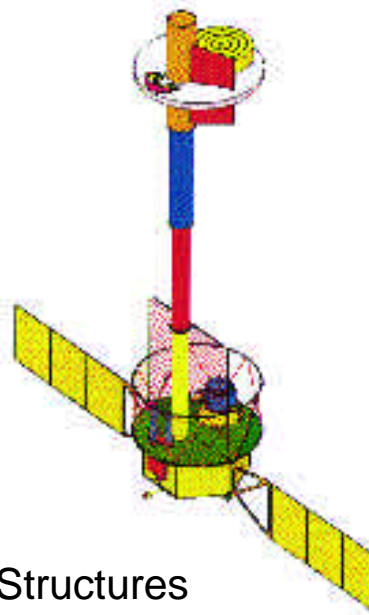
CdZnTe Arrays



Coolers

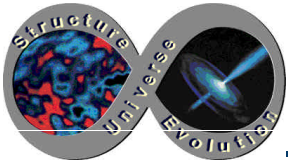


Deployable Structures



Autonomous  
Operations

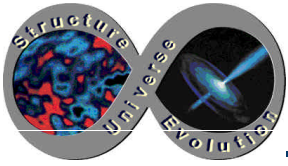




# HTXS Technology Roadmap & Mission Approach

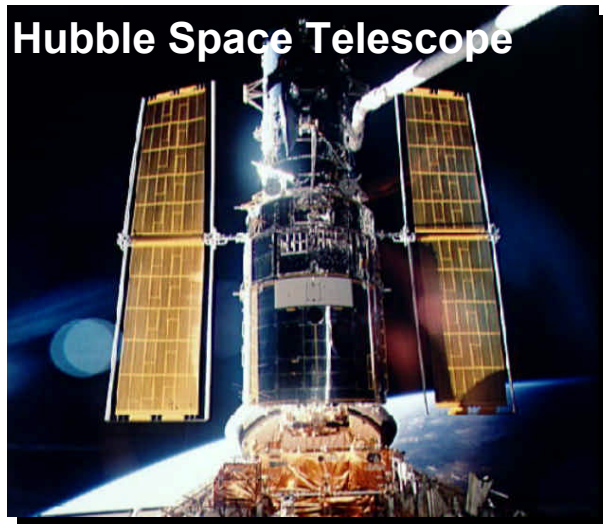
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- “Assembly line,” low-cost concept for six identical satellites requires demonstrated performance for key technologies before phase C/D
  - essential for managing schedule and cost
  - requires investment ramping from ~ \$5M to ~ \$15M per year
- Technology roadmap developed by HTXS SWG, using expert teams and direct experience from AXAF, XMM, and Astro-E
- Coordinating with other cutting edge missions (FIRST, NGST, New Millennium, etc.)

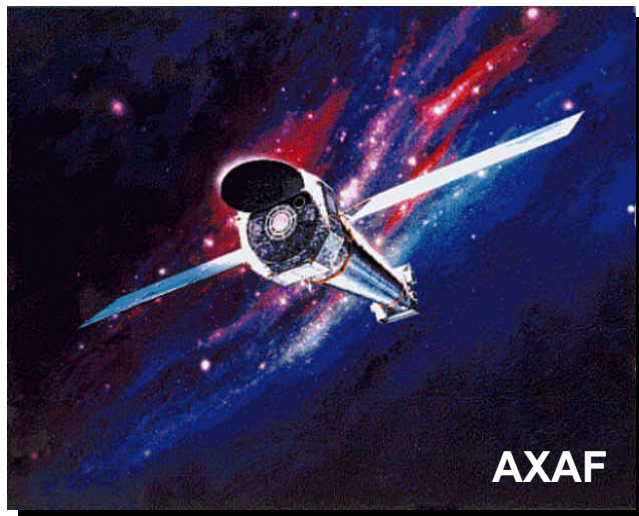


# Trade-offs: Angular Resolution vs Area

## Imaging



0.1 arc sec  
40,000 cm<sup>2</sup>

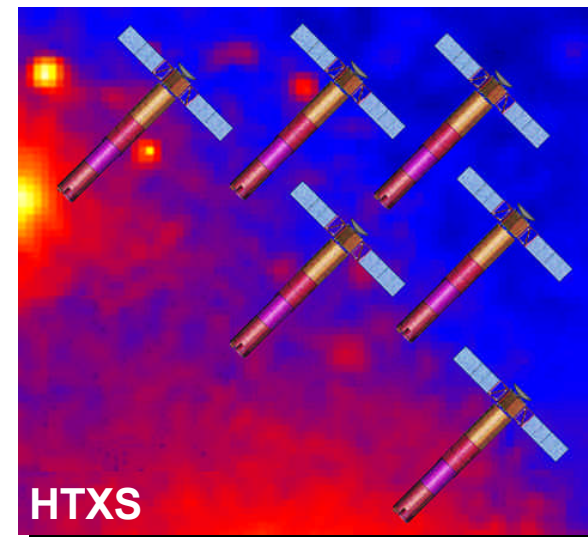


0.6 arc sec  
1,000 cm<sup>2</sup>  
(100 cm<sup>2</sup>)

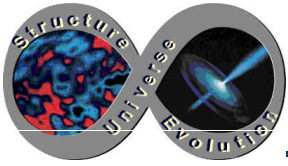
## Spectroscopy



1 arc sec  
780,000 cm<sup>2</sup>

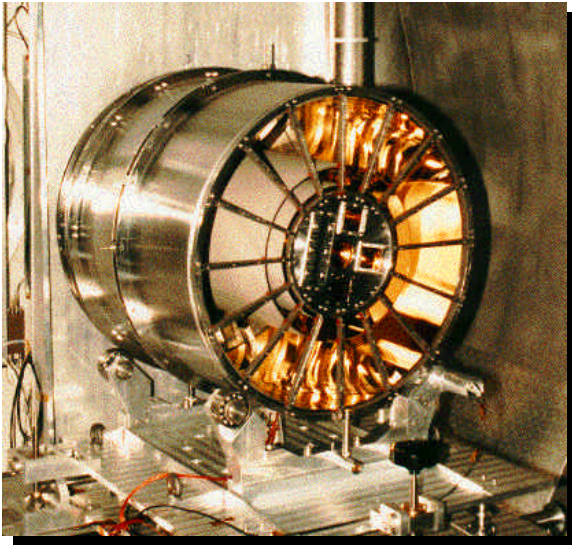


15 arc sec  
30,000 cm<sup>2</sup>  
(15,000 cm<sup>2</sup>)



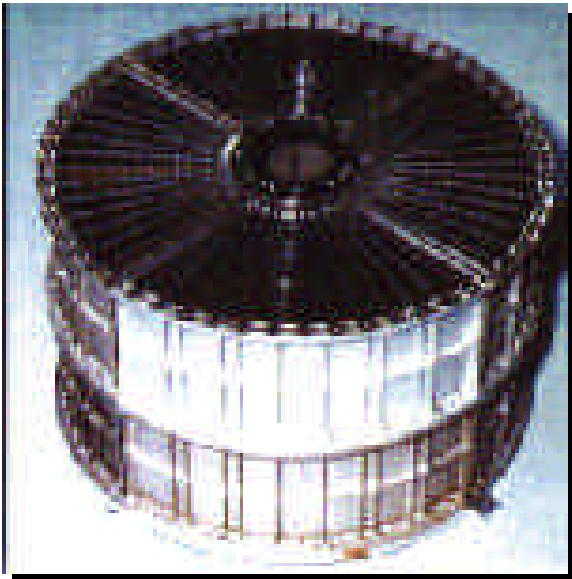
# SXT X-ray Mirror Design Alternatives

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## Replicated Shells (e.g., XMM):

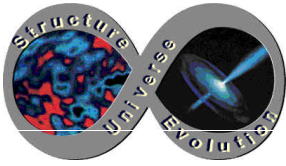
- meets 15" angular resolution
- requires factor of 10 weight reduction (2,500 kg --> 250 kg)
- investigate SiC, cyanate ester, and other lightweight carriers
- thin-walled rib-reinforced Ni shells



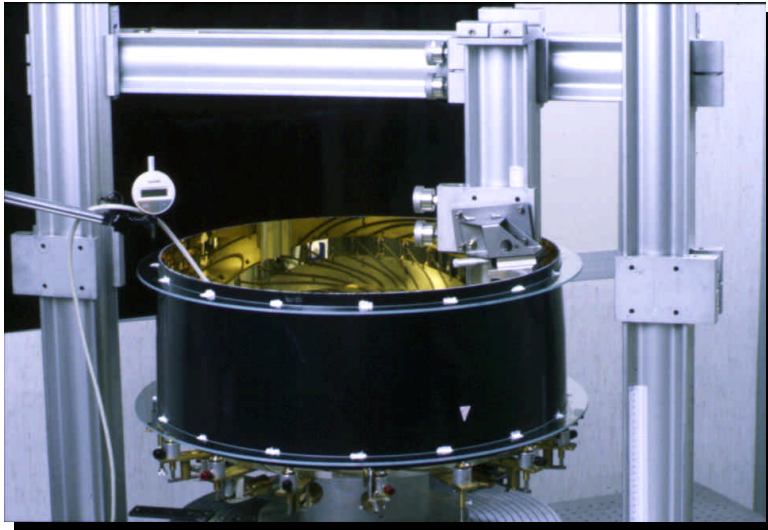
## Segmented Optics (e.g., Astro-E):

- 210 kg weight meets the requirement
- requires factor of 4 improved angular resolution
- improved mandrels and foil alignment techniques



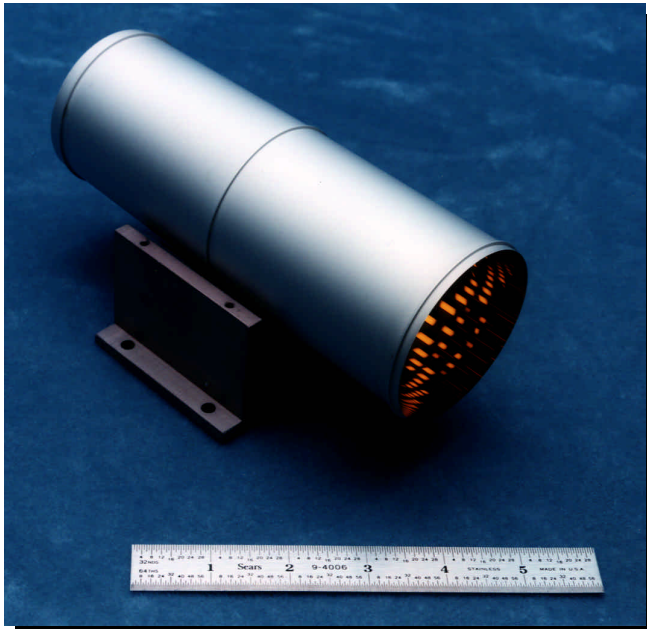


# Spectroscopy X-ray Telescope Progress on Replicated Shells



Alumina ( $\text{Al}_2\text{O}_3$ ) carrier shells produced in Italy at OAB -- lower temperature process, simpler, lower cost than SiC

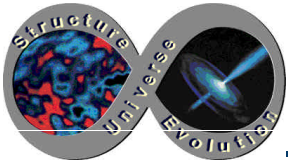
- Carrier with 600 mm diameter and 3.2 mm walls produced by plasma spray
- Optical surface replicated successfully -- X-ray test in August 97
- Lighter weight alumina carrier -- same diameter, 0.5 mm walls, three (3.3 mm) stiffening ribs
- Replicate this summer, then X-ray test



Progress on replicated shells at MSFC:

- Thin Ni shells with reinforcing ribs fabricated and ready for X-ray test
- Fabricated two 0.5 m diameter mandrels
- Modified equipment to handle 1.3 m diameter mandrels
- Awarded contracts for SiC and composite carriers

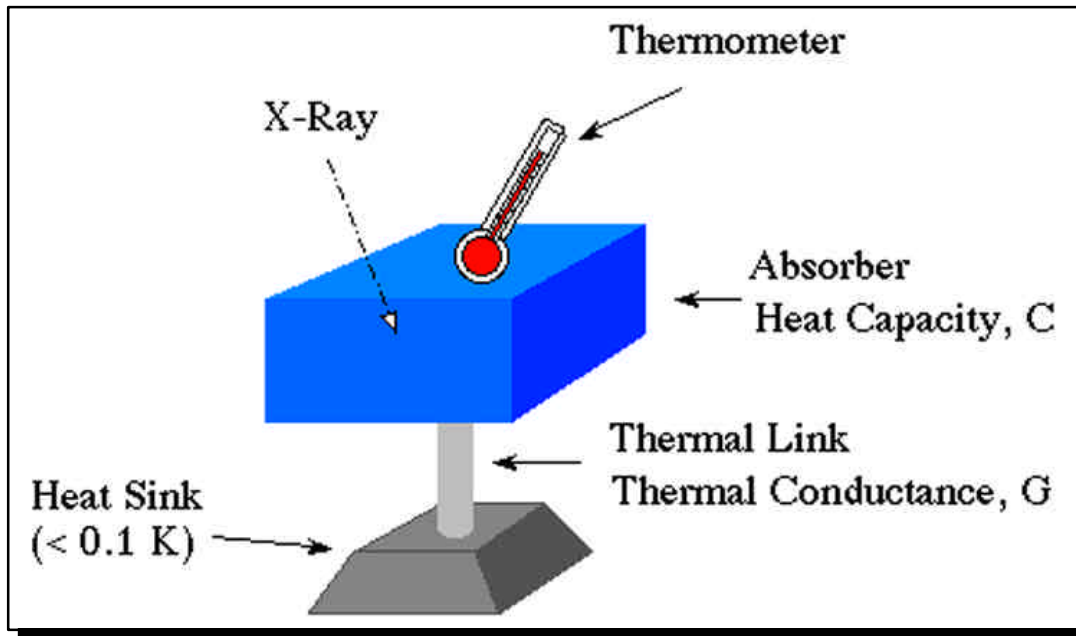




# HTXS Technology Roadmap

## Microcalorimeters

### Requirements on HTXS Microcalorimeter Array



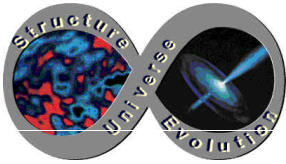
A detector with 2 eV spectral resolution over the 0.3 - 12 keV band

- High quantum efficiency (~99% at FeK)
- Imaging capability commensurate with mirror PSF
  - 2.5' FOV => 30 x 30 array
  - 10' FOV => 120 x 120 array
- Moderate speed for handling counting rates of 1 kHz or more

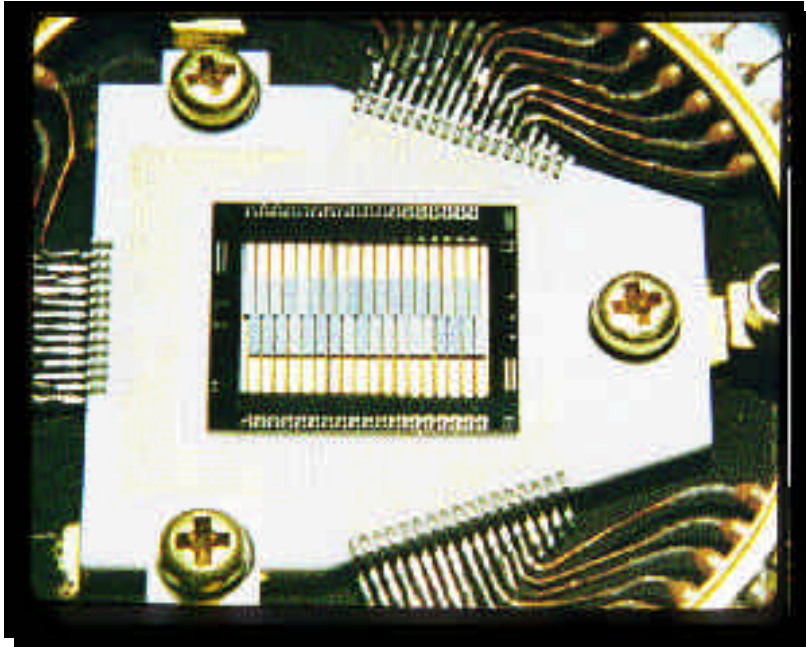
Current capability is 7-12 eV with 10 x 10 array

Technology developments required to achieve 2 eV resolution include

- more sensitive thermometers (transition edge superconductor)
- reduce heat capacity and power dissipation of existing system

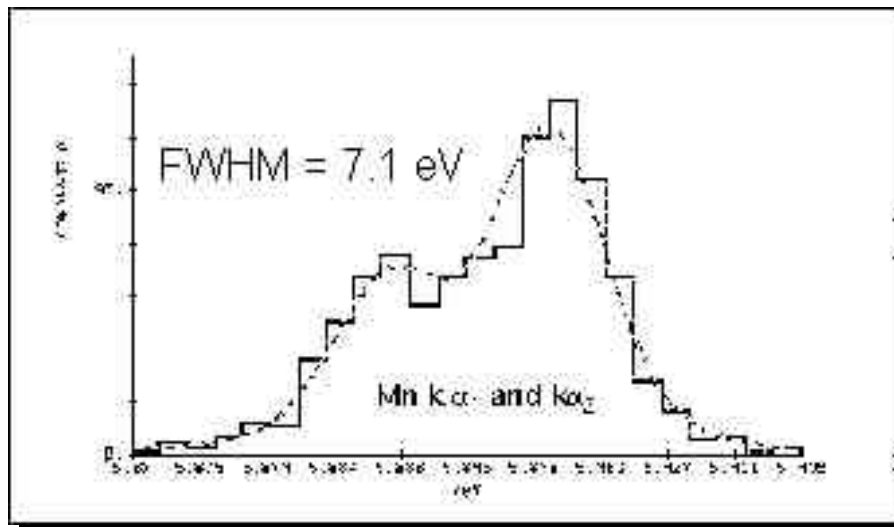


# HTXS Calorimeter Advances



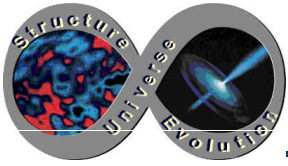
## First flight test of Microcalorimeter

- Wisconsin/GSFC rocket flight 06/96
- 36 pixel array operating at 60 mK
- Observation of diffuse X-ray background
- Resolution of 14 eV at 277 eV achieved
- Detection of Sulfur IX and Oxygen VII
- Next flight 8/97 with improved array



## First demonstration of TES Calorimeter at NIST

- Transition Edge Superconduction thermometer
- First result of 7.1 eV in Summer 1996 matches best to date
  - Capable of higher energy resolution
  - Higher counting rates
  - Lower cryogenic heat loads
- Not yet optimized!
  - expect significant improvement



# HTXS Technology Roadmap

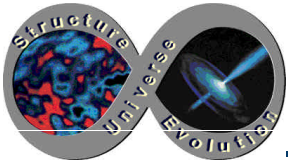
## Microcalorimeter Cooling System

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Develop long life, low weight, low cost, low vibration cooling systems



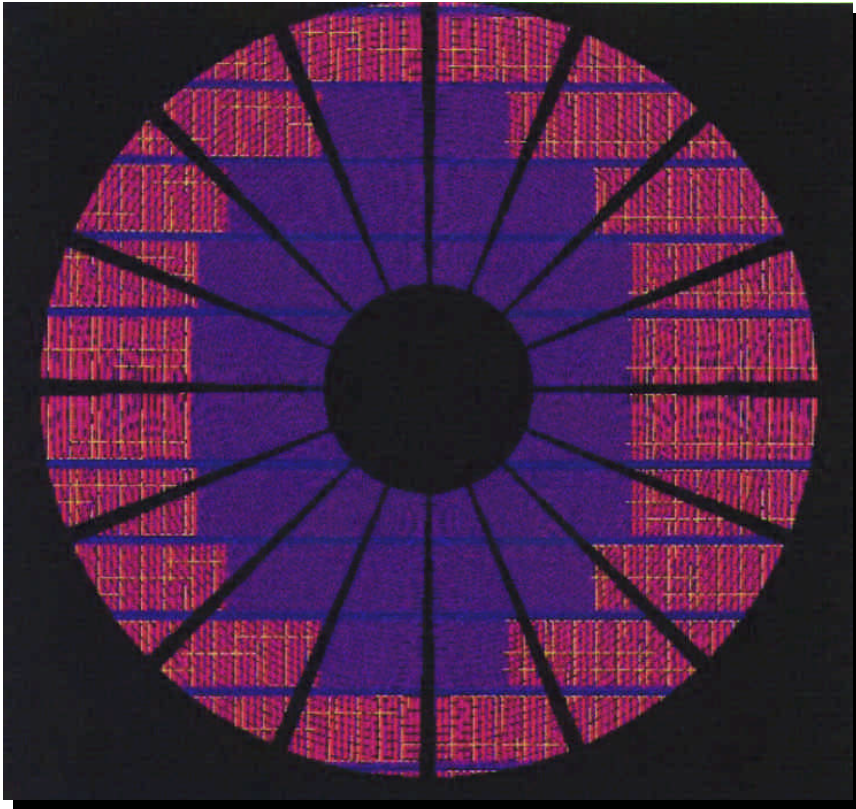
- Required Technologies
  - Mechanical cryocooler for thermal shields providing 10-100 mW cooling @ 3-5 K
  - Two-stage ADR system to reach 65 mK
- Investigate alternative technologies
  - Dilution refrigerator vs ADR
  - Sorption cooler vs Turbo-Brayton cooler
- Recent progress
  - Engineering model Turbo-Brayton 5 W, 65 K cooler run for 1.5 years with no degradation; being fabricated for 1999 HST servicing mission
  - 5-50 mW @ 4-10 K breadboard being fabricated with test in early 1998
- Require funding for two-stage ADR development



# HTXS Technology Roadmap

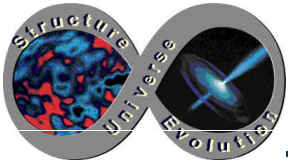
## Grating/CCD Spectrometer

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- The Grating/CCD spectrometer on HTXS will offer unprecedented sensitivity and resolution in the line-rich, low energy ( $E < 1$  keV) X-ray band.
- Effective area more than an order of magnitude better than that of the grating spectrometers on AXAF and XMM will be achieved.
- The design builds on the successful technical heritage of XMM and AXAF.
- Important new technology developments will include
  - Significant reduction in the mass per unit area of the grating array
  - Improved diffraction efficiency and reduced scattering from the individual grating elements
  - Significant reduction in the power consumption and total mass of the CCD and their associated read-out electronics
  - Improved low energy quantum efficiency in the CCDs





# HTXS Technology Roadmap

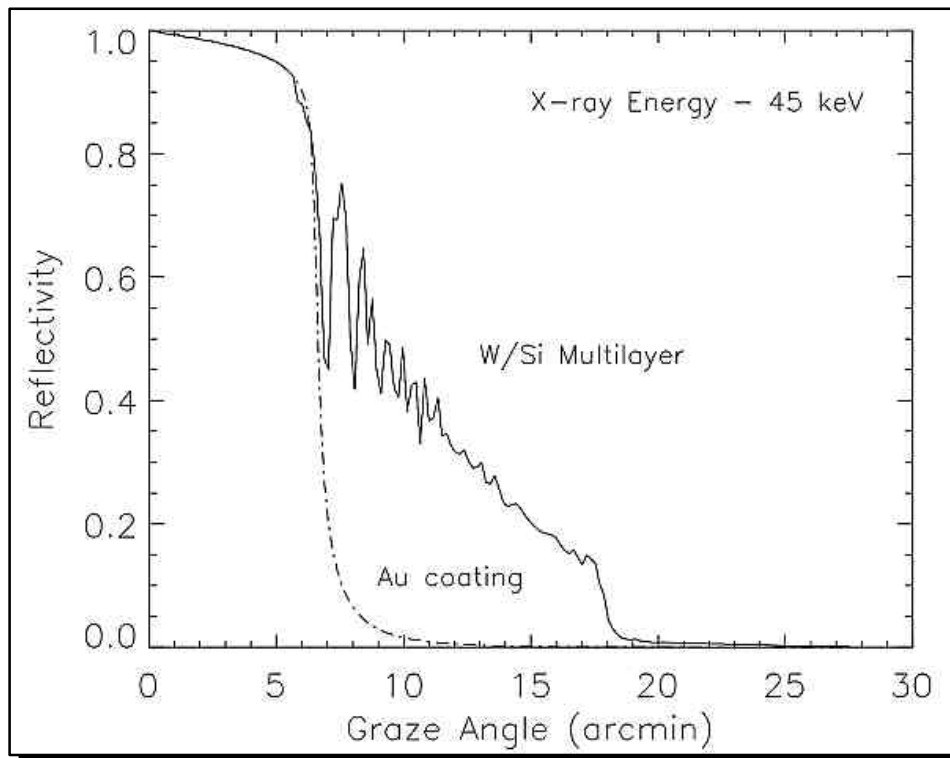
## Hard X-ray Telescope: Optics

### Primary Approach - Segmented shells

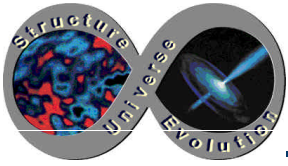
- Approach drawn from *ASCA*, *ASTRO-E*, *SODART*
- Epoxy replicated foils or thermally-formed glass substrates:
  - Mass ~ 100 kg achievable
  - Measured surface quality - 3.7 Å glass, 5.5 Å foils meets requirements

### Required technical development

- Demonstrate coating without distortion



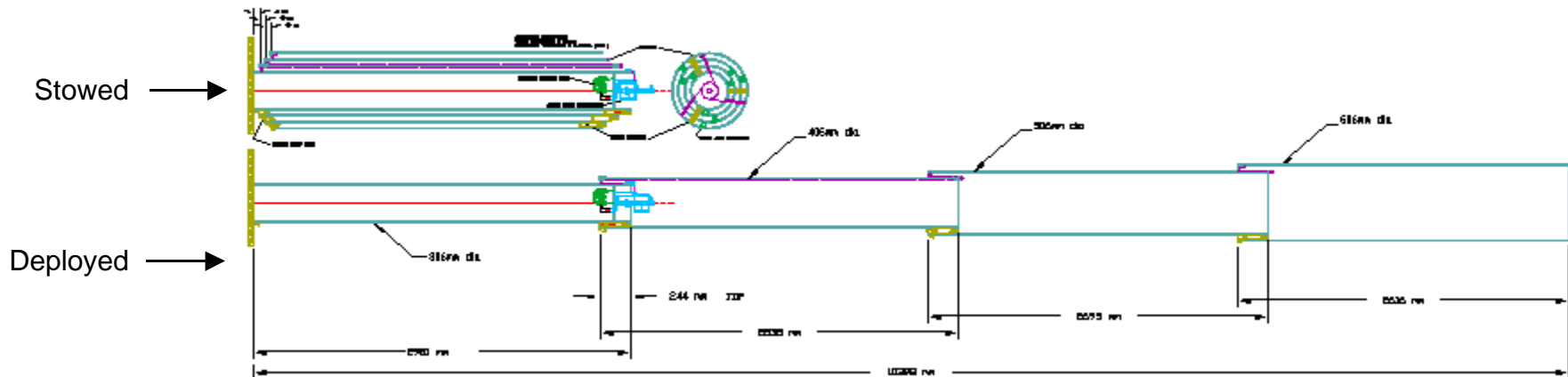
- W/Si multilayer on curved glass at Caltech/Columbia -- 200 layer pairs, 0.66 micron thick with acceptable stress
- Pt/C multilayer on an epoxy replicated foil mirror shell at GSFC/Nagoya -- 30 layer pairs, 0.13 micron thick with no distortion of foil due to stress
- Balloon flights planned in 1999
- Ray trace (left) indicates required area at 45 keV achievable



# HTXS

## Extendible Optical Bench (EOB)

EOB provides the platform or support between the mirrors and the detectors and maintains their respective alignment for the mission

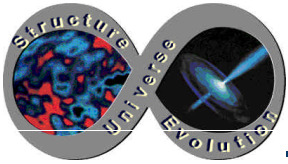


### HTXS Requirements

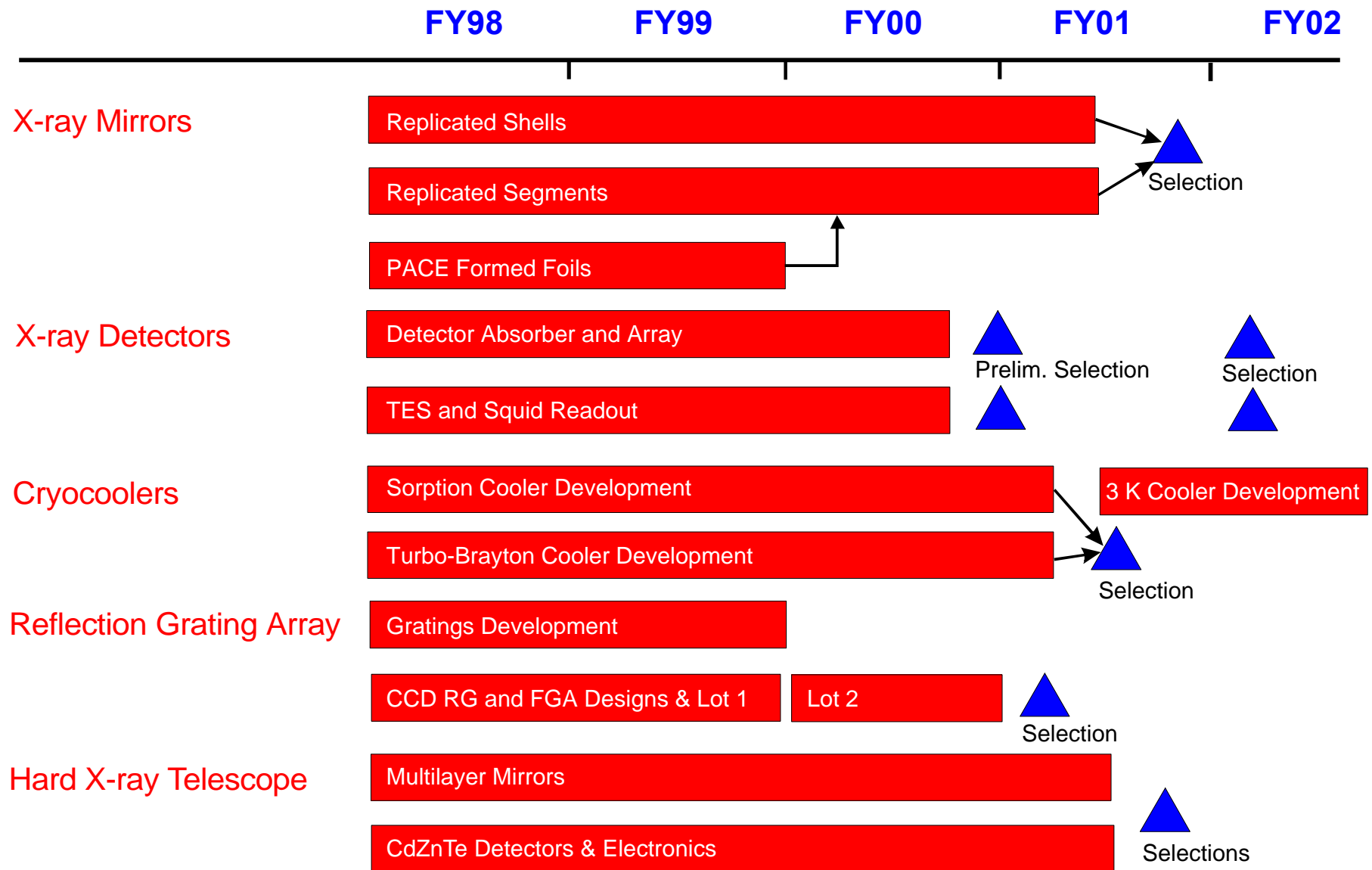
- Provide for a focal length of approximately 8.5 meters with a stable structure (~ 1 mm) both mechanically and thermally
- EOB deployable to utilize Delta II-class launch vehicle
- Provide light tight protection to SXT and Grating/CCD

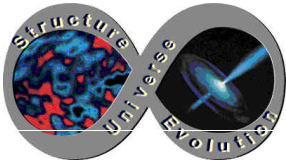
### EOB Development Status

- Awarded partial funding through GSFC Directors Discretionary Fund in 97
- Optical alignment sensing system demonstrated in the lab using off-the-shelf components
- Vendors have reviewed baseline tube structures and confirm approach is feasible
- Next step is to produce an engineering unit to demonstrate the system performance



# HTXS Technology Roadmap





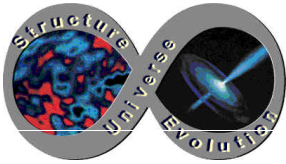
# HTXS Budget Requirements

Real Year \$ M

HTXS Mis s ion	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	De ve lop ment	Total
																<b>Total</b>	
Technology Develop.	0.6	5.6	11.1	14.3	15.4												47.0
Pre-Phase A	0.2	0.5	1.1	1.7	1.7												5.2
Phase A				0.7	2.4												3.1
Phase B						18.1	37.6										55.7
Phase C/D								78.1	108.2	111.3	114.4	73.5				485.4	485.4
Phase E											14.3	14.7	30.2	30.9	31.7		121.8
Launch Vehicle										65.4	67.2	69.0				201.6	201.6
<b>Total</b>	<b>0.8</b>	<b>6.1</b>	<b>12.2</b>	<b>16.6</b>	<b>19.6</b>	<b>18.1</b>	<b>37.6</b>	<b>78.1</b>	<b>108.2</b>	<b>176.7</b>	<b>195.9</b>	<b>157.2</b>	<b>30.2</b>	<b>30.9</b>	<b>31.7</b>	<b>687.0</b>	<b>919.9</b>
Above budget inflated to real year dollars																	

- Additional cross cutting cryo-cooler - \$1.6M in FY98
- Total development costs include Phase C/D and launch vehicle





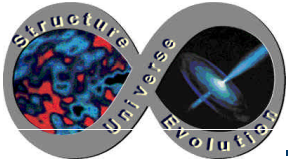
# HTXS Civil Service Manpower

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Civil Service	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
FTE	18	25	29	38	38	39	41	42	40	37	30

## Notes and Assumptions:

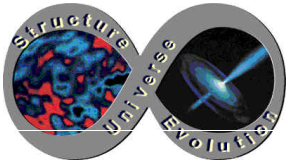
- HTXS Civil Service (CS) Manpower estimate is a WAG; will be refined as mission definition, program structure, and acquisition strategy evolve
- This estimate assumes Phase C/D/E development performed by industry/universities
  - GSFC performs mission management/integration
  - CS manpower will grow if hardware elements (e.g., detectors) are brought “in-house” as a result of technology development



# Mission Cost Fidelity

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- Current C/D cost estimate for HTXS mission including all six spacecraft and launch vehicles is \$538K in FY97 dollars
- Cost estimate is “bottoms up” by major technology system
- Each system cost has been estimated based on other missions (AXAF, Astro-E, XMM) and/or industry input
- The HTXS cost estimates will be refined over the course of next year as the mission concept develops



# The Outlook for HTXS

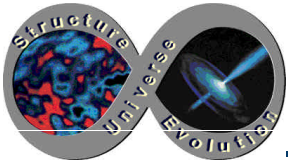
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## Summer of 1998...

- Technology development efforts have begun in earnest
- Mission concept study has demonstrated mission feasibility to next level of detail
- Cost estimates and Phase B/C/D schedule have been refined
- Acquisition strategy has been developed
- Outreach program underway

## Summer of 2002...

- Phase B is halfway complete
  - Mission contractor has been selected
  - Systems Requirements Review has just taken place
- Technology developments required for HTXS are complete
  - Selections made between competing technologies



## Associate Administrator Take-Away

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**HTXS** traces the evolution of the Universe from origins to endpoints

Investment required to develop advanced technology to enable the mission

- assembly line production of lightweight, high performance optics, detectors, coolers, and spacecraft

Multi-satellite concept is low-cost, low-risk

Facilitates ongoing science-driven, technology-enabled extensions:

- spatial resolution,
- collecting area,
- energy bandwidth, and
- spectral resolution